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(71) Applicant *(for all designated States except US)*: **THE ENSIGN-BICKFORD COMPANY** [US/US]; 660 Hopmeadow Street, P.O. Box 483, Simsbury, CT 06070-0483 (US).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **LEE, Robert, A.** [CA/CA]; 28 Crystal Beach Drive, Nepean, Ontario, K2H 5M8 (CA). **CHILDS, John** [US/US]; 10 Woodland Drive, Granby, CT 06035 (US). **SUTULA, Daniel, P., Jr.** [US/US]; 45A Grandview Drive, Farmington, CT 06032 (US). **DAYTON, Michael, A.** [US/US]; 1200 Buckpasser Court, Florissant, MO 63034 (US).

(74) Agents: **LIBERT, Victor, E.** et al.; Libert & Associates, 3 Mill Pond Lane, P.O. Box 538, Simsbury, CT 06070-0538 (US).

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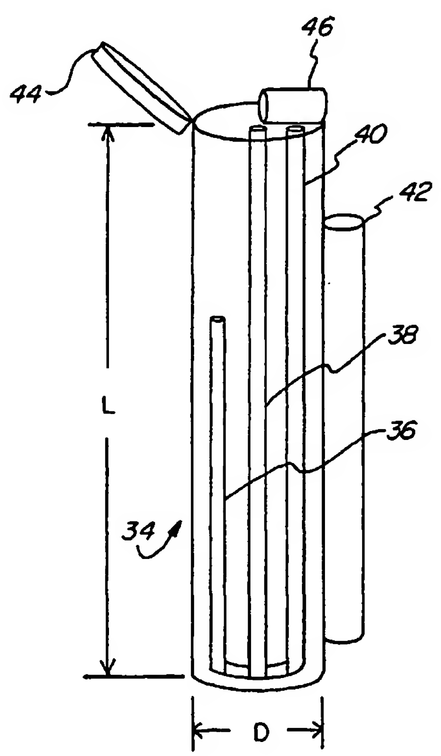
(54) Title: NARROW CAST BOOSTER CHARGES



(57) Abstract: The use of elongated booster or booster charges for initiating bulk explosives in boreholes provides advantages relative to conventional booster charges. Such booster charges are generally cylindrical in configuration and charges in accordance with this invention typically have a length-to-diameter ratio of at least 4:1, preferably greater than 4:1. In addition, the diameter of the booster charge is significantly less than the diameter of the borehole in which it is used, so that a significant amount of bulk explosive occupies the region in the borehole between the booster charge and the interior surface of the borehole. A vented stabilizer (14) is provided for combination with the booster in order to retain the booster centrally within the borehole. The stabilizer is preferably vented so that bulk explosive can flow through or past the booster and stabilizer assembly, and so that the assembly can be moved through the bulk explosive after the hole is filled.

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NARROW CAST BOOSTER CHARGES

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. provisional application number 60/310,990, filed August 8, 2001.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] This invention relates to cast booster charges (or "primers") of the kind typically used to initiate bulk explosives such as ANFO (ammonium nitrate/fuel oil) and relates in particular to the configuration of the booster charges and to an optional stabilizer accessory therefor.

Background

[0003] Booster charges and bulk explosives are typically used in boreholes or blastholes drilled into the earth. The booster is typically initiated by a detonator positioned in initiating relation to the booster (i.e., in a position in which the detonation of the detonator will detonate the booster charge), typically in a cap well in the booster. The initiation of the detonator follows from an initiation signal received via a downline fuse, e.g., detonating cord or shock tube to which the detonator is secured.

[0004] It is well-known that blastholes in production environments may contain significant amounts of standing water. This water may be present because the blasthole is not pumped dry prior to loading, or because it takes on a significant amount of water between the time the hole is pumped and the time the hole is loaded, or because it is left in the hole due to improper pumping technique or the use of faulty equipment.

[0005] It is also well-known that ANFO is ineffective when a significant amount of standing water is in the borehole because the ammonium nitrate prills are soluble in water. Emulsion blends are useful in providing a water-resistant product that can be bulk-loaded without borehole liners. Blasters commonly use, as a rule of thumb, blend proportions of 80/20 or 70/30 as a basis for making a water-resistant blend. However, research has shown that a 50/50 blend is necessary to achieve an acceptable velocity of detonation (VOD) under wet conditions. Some argue that even heavier blends are required due to the separation of the continuous emulsion phase from the prill material upon loading in the blasthole.

[0006] Loading of these blends is complicated by the fact that significant water occlusion may occur when the blasting agent is loaded, creating regions of explosive/water mix. Others (Schettler & Brashear (1996)) have conducted loading experiments in clear pipes and observed that with lighter blends (80/20, 70/30) the water mostly filled the interstitial spaces. With heavier blends (60/40, 50/50), however, water was not displaced entirely, but instead formed a liquid interaction zone where water was mixed with agglomerations of explosive. It was also observed that over sleep-times up to 10 hours, the water-filled voids would sometimes coalesce and grow, resulting in decoupling and possible internal separation of the explosive column. No observations of the behavior of the bulk explosive as it was loaded around a primer or the final nature of the explosive/primer contact was provided.

[0007] Repumpable emulsion blends are, in theory, more effective at displacing standing water as they are loaded into the hole. In practice, however, the technique is not as efficient as auger-loading from surface, because a loading hose must be deployed and retracted the full length of the column. Although more common in quarries and construction, the method becomes more impractical in large scale production environments, such as coal or surface metal operations. Even when used, repumpable blends may not effectively solve the problems associated with standing water, as significant water occlusion may still occur in the area of the primer as the explosive flows to fill the borehole.

[0008] There is a commonly held belief that the main mechanism of explosive priming is the transfer of a shock wave from the top surface of the primer to the blasting agent. This shock wave then causes regions of high heat and pressure to grow and coalesce within the explosive, and ultimately results in the rapid run-up to steady-state detonation. For this reason, it is thought that maximum priming efficiency is realized when the primer diameter is coupled as closely as possible to the borehole diameter (Dick, 1976; VanOmmeren, 1989; ISEE, 1998).

[0009] Research has shown that the run-up in ANFO is negligible (Dick, 1976; Torrance & Neill, 1990) and the run-up in emulsion and water-gel products is relatively consistent regardless of primer size, as long as the minimum recommended primer weight is used (Torrance & Neill, 1990).

[0010] While these rules and observations may apply for relatively sensitive blasting agents under relatively good conditions, they may not apply when the bulk explosives are relatively insensitive or have become desensitized through either transport, loading, or exposure to adverse environmental conditions. Kennedy (1990) showed through computer simulation that when priming sensitive blasting agents under good conditions, the shock wave off the top of the primer was sufficient to cause initiation of the explosive. In this case, he also showed that ini-

tiation of the bulk explosive from the sides of the primer caused a detonation wave to grow, reflect off the borehole walls, and progress up the borehole until it overtook and served to reinforce the initial detonation front. At this point a step occurred in the VOD at approximately 2 borehole diameters above the primer, at which the rate increased dramatically.

[0011] When simulating the initiation of relatively insensitive blasting agents, however, Kennedy demonstrated that the initial shock from the top of the primer induced only a weak chemical reaction in the bulk explosive. The reaction rate was observed to drop off quickly due to spherical divergence of the shock front, as the pressure caused by the reaction was insufficient to create a self-sustaining detonation front. Weak reaction fronts within the bulk explosive were also observed to initiate at the sides of the primer. These fronts were confined by and reflected from the borehole walls, and quickly overtook and reinforced the weak initial reaction front above the primer. This reinforcement was sufficient to build and accelerate the chemical reaction within the bulk explosive to the point that it was self-sustaining.

[0012] Extensive VOD measurements in a variety of operating environments showed that wet blastholes loaded with bulk blasting agents routinely demonstrate low VOD, deflagration, or even column failure. During day-to-day production, these performance issues may go undetected for a number of reasons, and usually have been compensated for in the evolution of the blast-design at the site. Occasional performance problems with the explosive products may manifest themselves in the following ways: excessive production of nitrogen oxides; high bottom and hard digging; poor fragmentation; excessive explosive use and inconsistent vibration levels.

SUMMARY OF THE INVENTION

[0013] This invention provides a cast booster charge having an effective length-to-diameter ratio (L:D ratio) of at least about 4:1. Optionally, the cast booster charge may comprise from about 450 to 2,270 grams (about 1 to 5 pounds) of explosive material.

[0014] According to one aspect of the invention, the cast booster charge may comprise a detonator well configured to position the output charge of a detonator about half-way between the ends of the booster, or at a distance from each end sufficient to permit the formation of a semi-planar detonation front at both ends upon initiation by the detonator.

[0015] According to another aspect of the invention, the cast booster charge may have a cylindrical configuration.

[0016] According to another aspect of the invention, the cast booster charge may be combined with a stabilizer comprising a base portion coupled to the booster charge and a vented skirt portion extending outward around the booster charge.

[0017] This invention also relates to a method of initiating a cast booster charge. The method comprises disposing a detonator in the booster charge at a distance from both ends sufficient to permit the formation of a semi-planar detonation front at the ends, and initiating the detonator.

[0018] Preferably, the detonator output charge is disposed at least about 11 cm (4¼ inches) from each end of the booster charge before initiating the detonator. Optionally, the detonator may be disposed in a cap well in the booster charge, about half-way between the ends of the cast booster charge. Optionally, the booster charge may be configured as described herein.

[0019] This invention also provides a method for initiating a charge of blasting agent in a borehole. This method comprises disposing a detonator in initiating relation to a cast booster charge having two ends and an effective L:D ratio of at least about 4:1, disposing the cast booster charge and the detonator in the blasting agent in the borehole, and initiating the detonator. Optionally, the booster charge may be configured and combined with the detonator and an optional stabilizer as described herein.

[0020] Also optionally, the booster charge may be configured to provide a clearance of at least about 5 cm (about 2 inches) from the borehole wall. Likewise, the borehole may optionally have a diameter of about three times the diameter of the booster.

[0021] The method might also comprise centering the booster charge in the borehole by mounting a stabilizer to the booster charge, the stabilizer comprising a base portion mounted on the booster charge and a vented skirt extending outward from the booster charge.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] Figures 1 through 4 are graphs showing the results of the velocity of detonation measurements made in the tests described in Examples 1, 2 and 3;

[0023] Figures 5A and 6A are schematic representations of the analytical model of the simulations described in Example 5 each showing only one-half of the represented structures to the right of central axis A;

[0024] Figures 5B-5F and 6B-6F are graphic representations of the data derived from the test apparatuses of Figures 5A and 6A;

[0025] Figure 7 is a perspective view of a booster-stabilizer assembly in accordance with a second aspect of this invention;

[0026] Figure 8 is a top view of the stabilizer seen in Figure 11;

[0027] Figure 9 is a partial elevation view of the assembly of Figure 11 in a borehole;

[0028] Figure 10 is a partial elevation view of a booster with rounded end caps in accordance with another aspect of this invention; and

[0029] Figure 11 is a schematic perspective view of a mold for making an elongated cast booster according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION AND PREFERRED EMBODIMENTS THEREOF

[0030] Variations in manufacturing of bulk blasting agents and the effects of storage, transport, loading and adverse borehole conditions may cause bulk blasting agents to be less sensitive than they are designed to be. As a result, the blasting agent may deflagrate or fail to initiate completely when primed with conventional cast booster charges (also sometimes referred to herein as "primers" or "boosters"). For example, the sensitivity of some blasting agents may be reduced when they are bulk-loaded into blastholes containing standing water. This has been observed to result in poor explosive performance and possibly even malfunction of the blasthole. In some cases, the explosives may become so insensitive that a self-sustaining detonation may be impossible. In other cases, however, the probability of achieving high-order detonation of an explosive column may improve when modified booster configurations are used.

[0031] One aspect of this invention relates to cast boosters which, in contrast to prior art cast booster charges, are configured so that they leave a significant amount of clearance between their cylindrical outer surface and the interior surface of the borehole in which they are disposed. The material from which the booster is cast may be any suitable explosive material; these are known in the art (e.g., "pentolite", a mixture of pentaerythritol tetranitrate ("PETN") and trinitrotoluene ("TNT")), as is the method for casting boosters, and so need not be described herein. This can be achieved by providing a booster charge having a relatively long and narrow configuration. As discussed herein, one advantage of such a configuration is that it permits bulk explosive to flow around the booster and thus permits the placement of the booster in the borehole before the bulk explosive (i.e., blasting agent) is poured therein. If there is water in the blasthole around the booster, the extra clearance increases the likelihood that a blasting agent, when loaded into the hole, will make contact with the side of the booster.

[0032] In contrast, prior art cast booster charges, which have cylindrical configurations with a typical length-to-diameter ratio of 1.6:1, are typically sized so that their cylindrical outer surface more closely approaches the wall of the borehole within which they are disposed, and do

not provide adequate clearance between them and the borehole wall to permit the flow of explosive around them. As a result, bulk explosive blasting agent that is loaded into a borehole after the prior art booster is in place may "bridge" at the top of the booster, i.e., become lodged between the booster and the borehole wall such that it does not flow into the clearance space between them, especially if the booster is disposed in standing water when the blasting agent is loaded into the borehole.

[0033] In contrast, cast booster charges according to one aspect of the present invention have a significantly reduced diameter. In preferred embodiments, the boosters of this invention have a greater length-to-diameter (L:D) ratio than prior art boosters. Typically, the boosters according to this invention have an L:D ratio of at least 4:1, which enhances the effectiveness of the booster. Such boosters also leave a significant clearance between the cylindrical surface of the booster and the interior wall of the borehole. Therefore, bulk explosive or water in the borehole can flow around the booster. This allows placement of the booster in the borehole before the loading of the bulk explosive material therein with reduced risk that bridging will occur. The L:D ratio may be as great as 10:1, or even 20:1, or greater.

[0034] The increased length (or height, assuming the usual vertical orientation in a borehole) of the booster may provide a higher probability of intimate contact with the bulk explosive, despite the presence of large pockets of entrapped water in the explosive column. When bulk blasting agents are loaded into blastholes with standing water, pockets of water may become entrapped within the blasting agent. The increased length of the booster may increase the likelihood that the booster will, at some point along its length, maintain intimate contact with the blasting agent, despite the presence of these water pockets, which would normally serve to buffer the pressure originating from the booster.

[0035] While it is possible to attain one aspect of this invention (i.e., increased clearance between the booster and a borehole wall) by providing a proportionally smaller booster charge than is normally used for a given size borehole, this would result in the use of less explosive in the booster, thus reducing the output of the booster and diminishing its effectiveness. Accordingly, in a preferred embodiment of the invention, the overall mass of explosive used in the booster charge can be roughly the same as for a conventionally configured booster charge by providing a booster charge with a large length-to-diameter (L:D) ratio (an "elongated booster"), e.g., an L:D ratio of at least 4:1, preferably greater than 4:1, especially for boosters in the 0.45 to 2.27 kilogram (kg) (1- to 5-pound) weight range. Such booster configurations have been found to be successful in initiating explosive columns under adverse conditions in which booster charges with prior art configurations failed.

[0036] As is well-known in the art, cast booster charges are formed by pouring molten explosive material into a cast (or mold) that are usually formed from paper or plastic. The shape and dimensions of the cast determine the final configuration of the booster charge. Generally, the cast is cylindrical, yielding a booster having a round side (i.e., a round cross section) and two ends including a top surface and a bottom surface. Figure 11 is a schematic perspective view of a booster mold that can be used in casting a booster charge configured in accordance with this invention. Mold 34 is generally cylindrical in shape, with a length L and a diameter D in accordance with the present invention, i.e., which have an L:D ratio of at least 4:1. Any intermediate dimensions for L and D may optionally be used, provided a suitable L:D ratio, ratio of borehole diameter to booster diameter or booster-borehole wall clearance, is achieved. A booster comprising 800 grams of pentolite with a density of 1.7 g/cc will comprise about 470 cubic centimeters (cc) of explosive material. A solid cylindrical body of this volume with an L:D ratio of 4:1 would have a length of about 21 cm (8.4 inches) and a diameter of about 5.3 cm (2.1 inches). The dimensions of a booster charge of this mass and proportions would be larger, due to the extra volume required for the throughbore and cap well that would typically be formed therein. A typical embodiment has a length of about 24.1 cm (9.5 inches).

[0037] Mold 34 defines a cap well 36 for receiving a detonator and, typically, an optional through tunnel 38 and optional slider tube 42 through either of which the downline detonating cord or shock tube can pass through the booster so that the detonator can be disposed upwards in the cap well 36. Preferably, the end of the cap well, which is where the output end of the detonator is expected to be positioned, is at a point halfway between the ends of the booster or, preferably, at least about 11 cm (4.25 inches) from each end of the booster, so that upon initiation, there will be sufficient mass above and below the detonator to permit the formation of a semi-planar detonation front in the booster. The cap well of the booster may be configured so that by inserting the detonator into the cap well until the output end of the detonator is at the end of the cap well, the detonator will be at the desired position. An optional lid 44 is provided to cover the booster charge explosive material in mold 34. Finally, mold 34 includes an optional pass through clip 46. A typical explosive material for use in the booster charge comprises pentolite, a mixture of TNT and PETN in proportions in which the percent of TNT may vary from about 38 to 62 percent.

[0038] One consequence of using such an elongated booster charge with a conventional detonator is that the distribution of the booster explosive around the detonator is different from that in a conventional booster. It is understood in the art that a reference to the position of a detonator in a booster indicates the position of the explosive output portion of the detonator

(usually the end of the detonator shell). This is because a detonator is typically made from a cylindrical shell that holds, at a closed end of the shell, a small charge of explosive material therein to provide the explosive output, and it is the location of that charge in the booster that affects the performance of the booster. The remainder of the shell may vary in length and may contain optional non-explosive components, e.g., an electrical or pyrotechnic firing delay element, a transducer, etc. For purposes of this discussion, the position of the end of the detonator is the position of the detonator. In a prior art booster, insertion of a detonator into a cap well of the booster places the output end of the detonator near the top of the booster, leaving little explosive material above the detonator. If a detonator is inserted in a similar cap well in an elongated booster according to this invention, there will be more booster explosive material above and below the output end of the detonator than there would be in the prior art booster. As discussed below, the conventional booster can generate a semi-planar detonation front only in a downward direction, but a booster according to this invention can generate such a front both upward and downward.

[0039] Upon detonation of the booster, a higher pressure is generated above the top surface of an elongated booster than above a conventional booster, because the dimensional configuration allows for the formation of a planar, steady-state detonation front within the booster, travelling up the vertical axis, which in turn transmits a larger primary shock pressure to the blasting agent above the booster. This increased pressure may build a stronger reaction zone in the blasting agent. Thus, the bulk of an elongated booster above the output end of the detonator relative to a prior art booster allows for generation and transfer of strong shock pressures from both above and below the detonator, with detonation fronts that travel both up and down the axis of the elongated booster. These pressures may promote the initiation of a reaction zone within the blasting agent on the sides of the booster, travelling in both the up and down directions. It has been shown through computer modeling that the reaction zone on the side of the booster may be confined by the borehole walls and accelerate to meet and reinforce the reaction zone created by the primary shock wave, which in turn may turn potentially weak reaction zones into a collective detonation front travelling both up and down the borehole.

[0040] Finally, in a booster charge in accordance with this invention, the detonator will, on average, be closer to the cylindrical outer surface of the booster than it would be in a prior art booster. In addition, the reduced diameter of an elongated booster relative to the blasthole may render the booster less prone to floating up the blasthole as the blasting agent is loaded, when the agent is pumped into the bottom of the hole.

[0041] Unless otherwise specified, the invention is described in detail herein in relation to regular right cylindrical cast booster charges, but this configuration is not considered a limitation on the invention. Non-cylindrical embodiments of this invention, e.g., oblong rectangular configurations, tapered configurations, etc., can be realized as well as right cylindrical ones. The term "effective L:D ratio" is intended to extend the L:D ratios of cylindrical boosters according to this invention to non-cylindrical boosters. To determine the effective L:D ratio of non-cylindrical embodiments, an "effective" diameter for the non-cylindrical booster charge may be determined so that the effective L:D ratio of the booster can be established. The effective diameter is the diameter of a circle having an area equal to the average cross-sectional area (taken in a plane perpendicular to the length axis) of the booster. For example, a booster may be in the form of an oblong rectangular block having a square cross section. The effective L:D ratio of such a booster would be the ratio of its length to the diameter of a circle having an area equal to the area of the square cross section. Thus, the term "effective L:D ratio" as used herein pertains to right cylindrical configurations (in which the actual cross-sectional diameter and L:D ratio are the same as the effective diameter and the effective L:D ratio, respectively), and a wide variety of other configurations.

Example 1

[0042] Velocity of detonation (VOD) measurements were made for a 50/50 pumped explosive emulsion blend in a limestone quarry. The loaded column was composed of multiple explosive decks, with the holes being more than 50 meters deep and containing significant amounts of standing water. The depth of the holes made pumping them prior to loading very impractical, so the explosive was pumped into the borehole using a hose inserted with its opening at the bottom of the hole in an effort to displace the water while loading the explosive into the hole. In most cases, conventional 450-gram cast boosters are used in the decks. It was found that most of the lower decks exhibited deflagration and low VOD on a regular basis.

Example 2

[0043] Further tests were conducted as described in Example 1, except for the following differences. As part of this testing, the bottom four decks of two holes within a production blast were loaded with the 50/50 blend. In one of the holes, each deck was primed with a comparative 900-gram cast booster with a length-to-diameter (L:D) ratio of 1.6:1. In the second hole, each deck was primed with a long 800-gram cast booster, having an effective L:D ratio of 4.6:1 in accordance with this invention.

[0044] There were no observed differences in either environmental or loading conditions between the two holes other than the change in boosters. The VOD records from each of the holes are shown in Figures 1 and 2 respectively.

[0045] In the case of the hole primed with the shorter (comparative) primers (Figure 1), the record clearly shows that all four explosive decks experienced deflagration, with an average rate of reaction of 640 meters per second (m/s). The hole primed with the longer boosters, however, resulted in more successful performance. The VOD record (Figure 2) shows the detonation of three of the four decks, with an average VOD of 4,200 meters per second (m/s). The bottom deck of this hole, Deck #1, detonated but did not show up at all on the VOD record, either as a deflagration or a detonation.

[0046] These data show that efficient priming, under these extreme conditions, was not accomplished by simply using a heavier cast booster, but instead by also employing a modified primer shape. Successful initiation of the bulk explosive was achieved by using a lighter primer with an effective L:D ratio of roughly twice that of the primers used in normal production blasts.

[0047] It should be noted that the testing included some holes loaded with specific bulk explosive formulations, which resulted in poor performance in all of the decks, regardless of primer used. Other holes, loaded with the bulk product formulation in a packaged configuration, were also included. It was found that the decks loaded with these chubs performed very well, with almost all decks functioning high order regardless of primer configuration. It is therefore clear that under some conditions, and with some bulk or packaged products, there is a high probability of success regardless of the primer configuration, while in more difficult conditions or with inappropriate products there may be virtually no chance of achieving reliable performance. Under other conditions, however, the difference between success and failure may reside in the use of a booster charge configured as taught herein.

Example 3

[0048] Another limited series of tests were run at a coal mine. In one test, a sub-scale blast was detonated using two different primer configurations: a standard (comparative) 900-gram cast primer with an effective L:D ratio of 1.6:1, and an 800-gram cast primer with an effective L:D ratio of 4.6:1. The holes were very wet, and despite being pumped prior to loading, contained a significant amount of standing water. The holes were auger-loaded using a 50/50 blend.

[0049] Four holes within the 6-hole blast were monitored for VOD. Unfortunately, two of the holes resulted in a poor record, because the safety primer cut off the VOD probe before it could record the detonation of the bottom primer. The results for the remaining two holes are given in Figures 3 and 4.

[0050] The record for the hole primed with the standard booster (Figure 3) clearly shows the detonation of the bottom primer and the detonation of the safety primer a short time later. No VOD trace was recorded for the explosive column immediately above either primer, indicating that the explosive either deflagrated or failed to initiate altogether. The record for the hole primed with the elongated booster (Figure 4) clearly shows the detonation of the bottom booster, followed by initial detonation of the bulk explosive at a rate of 4,650 m/s, which decays to a VOD of 3,130 m/s. The record also shows the safety primer detonating about 3 milliseconds (ms) after the bottom primer, which is followed by a VOD of 3,260 m/s in the bulk explosive. The difficulty in priming and maintaining a good VOD in the explosive was likely due to a combination of the standing water in the hole and the poor confining capabilities of the weak overburden material.

Example 4 (Analysis Of Loading Characteristics In Wet Boreholes)

[0051] In order to more fully understand the behavior of bulk explosive as it is loaded around a primer in a borehole, a small series of tests were done, as follows. A borehole was simulated using a clear plastic tube with an internal diameter of 146 mm and a length of 2.4 m that was capped at one end and filled to 1.2 m with water. The tube was fixed with a funnel at the top to simplify loading by a bulk truck fitted with an overhead auger. An inert primer assembly was loaded in the tube such that it was completely submerged in the water. A 50/50 blend was then auger-loaded into the tube until the tube was filled with the explosive/water mixture. The mixture was then allowed to settle for some time until movement or settling could no longer be detected; on average, about 5 minutes.

[0052] The following primer configurations were tested: a test 800-gram cast primer with an L:D ratio of 4.6:1 according to this invention, a comparative 900-gram cast primer with an L:D ratio of 1.6:1, and a comparative 450-gram cast primer with an L:D ratio of 2.1:1. A solid cylinder of 800 grams of explosive with a density of 1.7 g/cc and an L:D ratio of 4.6:1 would have a diameter of about 5 cm (2 inches) and a length of about 23.3 cm (9.2 inches), whereas a solid cylinder of the mass and proportions of the 900 gram comparative booster would have a diameter of about 7.5 cm (3 inches) and a length of about 12 cm (4.7 inches). A cylinder corresponding to the 450 gram comparative booster would have a diameter of 5.4 cm and a length of

11.4 cm. The actual boosters will vary slightly from these dimensions to account for the spaces provided therein for a cap well and a cord well. Typical cap wells and cord wells have diameters of about 0.8 cm (0.315 inch); a cord well extends for the length of the booster, the cap well extends for about half the length of the booster, as shown in Figure 11. For the tests, molds for boosters of these configurations were filled with plaster since no detonation was planned. Because the plaster was less dense than the water, a small weight had to be attached to the primers with a section of inert shock tube in order to prevent the primers from floating.

[0053] In each test, when the 50/50 blend was loaded into the tubes, the explosive would free-fall into the tube until it hit the standing water. At this point the blend would tend to separate into 7 to 13-cm "globs" (i.e., agglomerations), which would settle slowly through the water column. As these agglomerations settled on top of each other, large pockets of water would become entrapped in the explosive column. The progressive build of the explosive column would displace some water while entrapping the remainder, resulting in an explosive/water mixture.

[0054] In the test with the test 800-gram primer, which provided a clearance of about 4.8 cm (1.9 inches) from the tube wall, with a tube diameter to primer diameter ratio of about 2.9:1, it was found that the first few small agglomerations of blend fell past the primer and accumulated at the bottom of the tube, before some large agglomerations became lodged above the primer causing a bridge in the explosive column. The bridged area was quite delicate and mild agitation (tapping) on the side of the tube was all that was required to dislodge it and cause the blend to settle around the primer. It is expected that with a larger explosive column height, and possibly some heavy stemming material, the blend would have settled naturally without agitation.

[0055] Once the explosive had settled, it was found that there was a significant amount of water entrapped in the area surrounding the primer. Despite this, there were also regions of good contact with the bulk explosive. It appears from the test that the length of the primer was quite favorable compared to the characteristic size of the water inclusions, as the primer would be able to maintain good contact with the explosive regardless of where it was located within the loaded column. With a shorter primer, however, there were areas within the column in which the primer could be almost entirely surrounded with water.

[0056] In the test with the comparative 900-gram primer, which provided a clearance of only about 3.5 cm (1.4 inch) from the tube wall, with a tube diameter to primer diameter ratio of only about 2:1, many of the same phenomena were observed. In this test, however, the bridge created above the primer was quite strong, and jigging of the primer was required in or-

der to settle out the column. Although it is somewhat difficult to see in Figure 8B, there were large water inclusions surrounding the primer, even once the blend had settled. This shows that a clearance of greater than 3.5 cm, e.g., 4 cm or greater, or 4.5 cm or greater, etc., is effective to avoid troublesome bridging.

[0057] Unfortunately, the tube became progressively more contaminated with emulsion, and progressively less transparent as the testing proceeded, so the tests with the 450-gram comparative primer, which was tested last, were very difficult to interpret.

[0058] From these tests three important observations were made regarding the interaction of the bulk explosives, the primer and standing water within the borehole. First, significant water inclusions are produced within the explosive column as the blend is loaded by auger. These inclusions undoubtedly affect the density and sensitivity of the explosive. Second, these inclusions were also evident in the area immediately surrounding the primer and likely have an affect on the transfer of shock energy from the primer to the blasting agent. Third, bridging of the explosive above the primer occurred with all primer configurations (i.e., the bulk explosive could not flow through the clearance between the booster and the borehole wall), but the comparative larger diameter 900-gram primer appeared to produce a much stronger bridge.

Analysis Of Priming Characteristics

[0059] From the modeling work done by Kennedy discussed above, it can be inferred that under "normal" conditions with a relatively sensitive blasting agent, the key priming mechanism is the transfer of a shock wave from the top of the primer to the bulk explosive. In a relatively insensitive blasting agent, however, this primary shock wave is insufficient to produce a detonation front within the explosive, and must be reinforced by stronger secondary shock wave produced from the sides of the primer, to achieve a steady-state detonation.

Example 5

[0060] The detonation of the two cast primers in a 150-mm borehole was simulated using Autodyn-2D (Century Dynamics Incorporated) computer modeling system. One of the modeled configurations was for a test 800-gram primer 10 (Figure 5A) with an L:D ratio of 4.6:1 and a comparative 800-gram primer 30 (Figure 6A) with an L:D ratio of 1.8:1 according to this invention. The same primer mass was used for each test in an attempt to isolate the effects of the L:D ratio. Both primers 10 and 20 comprised cast pentolite having a density of 1.7 grams per cubic centimeter (cc) for a volume of about 470 cc, a detonation pressure of 25.5 GPa, a detonation energy of 8.1 GJ/m^3 and a VOD of 7530 m/s. Therefore, as discussed above in Ex-

ample 4, primer 10 according to this invention would have a diameter D of about 5.07 cm (2 inches) and a length L of about 23.3 cm (9.17 inches), and comparative primer 30 would have a diameter D of about 6.93 cm (2.73 inches) and a length L of about 12.47 cm (4.9 inches). No blasting agent was included in the simulation. Instead, the model simulated the primers being submerged in standing water 16 in 15 cm diameter boreholes, similar to a confined underwater detonation test. Therefore, if the primers were assumed to be centrally disposed within the borehole, primer 10 would have a clearance C_{10} of about 5 cm between the side of the primer and the borehole wall while the primer 30 would have a clearance C_{30} of only about 4 cm (1.59 inch). The ratio of the borehole diameter to the diameter of test primer 10 was about 3:1, while the corresponding ratio for the comparative primer 30 was about 2.16:1. If a centrally positioned booster provides a minimum clearance from the borehole wall that is effective to avoid bridging, the displacement of the booster in the borehole from the central position will create a lesser clearance on one side of the booster but a greater clearance on the other side, and the greater clearance will compensate for only bridging permitted by the lesser clearance. The confining material around the borehole was specified to be rock 18 with a density of 2.85 g/cc, a bulk modulus of 43.52, a sheer modulus of 22.57 GPa, a UCS (unconfined compressive strength) of 247 MPa and a tensile strength of 19 MPa. Five virtual tracer points 20, 22, 24, 26 and 28 were simulated at locations 5 mm from the surface of the primer, with two located on the axis of symmetry above and below the primer, and three located at one-quarter intervals along the side of the primer. (Note that Figures 5A and 6A show only one-half of the borehole and primers shown therein, omitting what would normally be shown at the left side of central axis A.)

[0061] The results of the simulations are shown in Figures 5B-5F and 6B-6F, which show the projected pressure vs. time plots for the various virtual tracer points. The data in these plots indicate that the detonation of the standard-length (comparative) primer 30 would begin at the initiation point 12' and progress spherically until it contacted the free surface at the top of the primer. The detonation front would then progress tangentially in a divergent pattern along the top surface until reaching the sides of the primer. Because the detonation front would not yet develop into a planar front, the pressure transmitted to the water from the top surface would be relatively low at 2.2 GPa. The detonation front would reach the sides of the primer and the spherical front would continue to progress downward as it flatted into a semi-planar front. The pressures imparted into the water at the side of the primer would be relatively consistent at 4.3 GPa, 4.4 GPa, and 4.3 GPa as shown in Figures 5C-5E. Finally, the detonation front would

erupt out of the bottom surface of the primer and impart a pressure of 4.4 GPa in the water, twice as high as the pressure experienced at the top surface of the primer.

[0062] The detonation of the longer primer 30 would begin at the initiation point 12', just below the axial center of the booster, and would progress spherically until the detonation front reached the free surface at the side. The virtual tracer point at this location (point 36) would experience a peak pressure of 3.8 GPa (Figure 6D). Two detonation fronts would then develop, with one travelling up and the other travelling down the length of the primer. These fronts would both develop into semi-planar fronts and, as they passed the upper and lower tracer points on the side of the primer (points 38 and 34), would impart a peak pressure of 3.9 GPa (Figures 6C and 6E). Finally, the detonation fronts would reach the upper and lower surfaces of the primer 30 and result in peak pressures at the upper and lower tracer points (points 40 and 32) of 4.1 GPa and 3.9 GPa respectively.

[0063] It is likely that the peak pressures at the sides of the longer primer 30 would be lower than those expected for the shorter primer 20, because of the difference in radius between the two configurations. The longer primer 30 has a smaller radius, which promotes greater divergence of the shock front imparted to the water, resulting in slightly lower peak pressures at the tracer points. The peak pressure at the top surface of the longer primer 30 is expected to be almost twice that of the shorter primer 20, because the configuration allows the detonation front to develop into a planer front. The pressure expected at the bottom of the longer primer 30, however, is slightly lower than that of the shorter primer 20. This is likely due to the larger surface area of the shorter configuration and its effect on the divergence of the shock front.

[0064] These simulations suggest that two factors contribute to the success of the longer primer configurations in the field-testing. Without wishing to be bound by any particular theory, it is believed that the longer configuration allows for the growth and development of a planar detonation front travelling in the upward direction. This, in turn, results in greater peak pressures imparted to the blasting agent at the top of the primer, thus encouraging the development of a stronger reaction front in the explosive. Further, the longer configuration encourages the development of two detonation fronts, one moving up and one moving down the axis of the primer from the location of the detonator. In contrast, the shorter configuration only develops a planar detonation front moving in the downward direction because there is insufficient explosive mass above the detonator to generate an upward moving detonation front. If the reaction fronts generated in the blasting agent on the sides of the primer follow the direction of the initial shock wave from the primer, then the shorter primer would develop a reaction front biased to travel down the borehole. The longer configuration, however, tends to develop reaction

fronts travelling both up and down the borehole. These fronts may then act to reinforce the primary reaction zones at the top and bottom surfaces, eventually leading to high-order detonation of the explosive in both directions.

[0065] Another aspect of this invention relates to a stabilizer that may optionally be secured to either a prior art booster or an elongated cast booster charge as described herein. The stabilizer has a central base portion that is coupled to the booster charge and a surrounding skirt portion that extends radially outward in the region around the booster charge. The stabilizer is vented or perforated so that bulk explosive (or "blasting agent") or water in the borehole can flow through the stabilizer and, conversely, the booster charge and stabilizer can move through a fluid column of water and/or blasting agent. However, the stabilizer imposes a drag on such relative motion between the booster charge and the fluid material in the borehole. The stabilizer is especially useful for booster charges that have been positioned in standing water before the bulk explosive is loaded into the hole because, as the explosive co-mingles with the water, a turbulence is created that can cause a non-stabilized booster charge to float upward with the interface between the water and the blasting agent, thus moving out of the desired position. The stabilizer, by providing drag against movement of the booster charge in the fluid column, can prevent such displacement. A second benefit of the stabilizer is that it helps to position the booster centrally within the borehole, thus preventing the booster from bearing directly against the interior surface of the borehole. By disposing the booster more centrally within the borehole, the likelihood that the booster will be completely surrounded with the blasting agent is greatly improved.

[0066] A booster and stabilizer assembly in accordance with one embodiment of this invention is shown in Figures 7, 9 and 10 (not to scale); the stabilizer itself is shown in Figure 8. Booster and stabilizer assembly 10 comprises a booster 12 having an L:D ratio greater than 4:1 (in this case, 4.6:1) although, as stated above, such an assembly might comprise a convention cast booster. A stabilizer 14 is mounted on booster 12. Stabilizer 14 defines a base portion 16 that is dimensioned and configured to securely receive booster 12 therein. Base portion 16 is situated within a vented surrounding skirt portion 18. Skirt portion 18 extends radially outward from base 16. Vented skirt 18 is preferably formed from a resilient material that can flex to accommodate minor imperfections in the interior surface of the borehole. In the illustrated embodiment, skirt portion 18 comprises a plurality of curved vanes 20 that diverge outwardly from booster 12 and then curve back inwardly to their ends. The vanes 20 are disposed radially about base 16 and are spaced apart from one another so that they define vents 22 between them. Several of vanes 20 are equipped with brace members 26 that bear against booster charge 12

and provide structural support for the portion of the vane closest to base 16. The inward-curved ends of vanes 20 are joined together by a support ring 24 which has a diameter slightly smaller than the greatest diameter encompassed by vanes 20. The exterior surfaces of vanes 20 define curved contact surfaces that can bear against, and easily slide along, the interior wall of a borehole. The curved configuration of vanes 20 permits assembly 10 to be inserted into a borehole and easily moved within it even though stabilizer 14 may bear against the interior surface of the borehole.

[0067] Figure 9 provides a schematic elevation view of the booster and stabilizer assembly 10 in a borehole in which arrows 28a indicate a possible downward flow path for bulk explosive/blasting agent material to flow around booster 12 and through vents 22 in stabilizer 14, and arrows 28b indicate the possible upward flow path through stabilizer 14 for water that may be displaced by the bulk explosive.

[0068] The stabilizer of the present invention, by providing flow paths around the booster charge, permits the placement of one or more booster charges in the borehole and the filling of the hole thereafter, because the bulk explosive and water can flow around the booster charge while preventing the booster charge from floating upward on the turbulent interface of displaced water and bulk explosive (blasting agent).

[0069] To further facilitate the flow of water and/or bulk explosive around the booster charge and through the stabilizer of the booster and stabilizer assembly according to this invention, one or both ends of the booster charge may be provided with a rounded or tapered configuration instead of the conventional flat configuration. For example, in the embodiment shown in Figure 10, base 16 includes a contoured cap 30, which would facilitate the downward movement of booster and stabilizer assembly 10 through standing water or bulk explosive in the borehole. Similarly, rounded top cap 32 will facilitate the flow of bulk explosive around the booster 12 as the explosive flows downward past booster and stabilizer assembly 10 or as the assembly moves upward through the explosive.

[0070] In the embodiment of Figures 7-10, vanes 20 are disposed with their broad, flat structures facing the booster charge. In an alternative configuration, the vanes could be disposed with their broad surface facing circumferentially about the booster charge. In other words, the vanes could be configured as enlarged versions of brace members 26. Such a configuration would reduce the resistance imposed by the stabilizer on water or bulk blasting agent flowing therethrough relative to the illustrated embodiment.

[0071] While the invention has been described with reference to particular embodiments thereof, it will be understood by one of ordinary skill in the art upon a reading and understand-

ing of this disclosure that various alterations and variations on the disclosed embodiments can be made and would fall within the spirit of the invention and the scope of the appended claims.

THE CLAIMS

What is claimed is:

1. A cast booster charge having an effective L:D ratio of at least about 4:1.

2. The cast booster charge of claim 1 comprising from about 450 to 2,270 grams of explosive material therein.

3. The cast booster charge of claim 1 or claim 2 comprising a detonator well configured to position the output charge of a detonator about half-way between the ends of the booster.

4. The cast booster charge of claim 2 having an effective L:D ratio of about 4.6:1.

5. The cast booster charge of claim 1 having a cylindrical configuration.

6. The cast booster charge of claim 1, claim 2 or claim 3 in combination with a stabilizer comprising a base portion coupled to the booster charge and a vented skirt portion extending outward around the booster charge.

7. A method of initiating a cast booster charge comprising disposing a detonator in the booster charge at a distance from both ends sufficient to permit the formation of a semi-planar detonation front at the ends, and initiating the detonator.

8. The method of claim 7 comprising disposing the detonator at least about 11 cm from each end of the booster charge before initiating the detonator.

9. The method of claim 8 comprising disposing the detonator in a cap well in the booster charge, about half-way between the ends of the cast booster charge.

10. The method of claim 7, claim 8 or claim 9 wherein the booster charge has an effective L:D ratio of at least about 4:1.

11. A method for initiating a charge of blasting agent in a borehole, comprising:

disposing a detonator in initiating relation to a cast booster charge having two ends and an effective L:D ratio of at least about 4:1;

disposing the cast booster charge and the detonator in the blasting agent in the borehole; and

initiating the detonator.

12. The method of claim 11 wherein the cast booster charge comprises from about 450 to 2270 grams of explosive material.

13. The method of claim 11 or claim 12 comprising disposing the output charge of the detonator at least about 11 cm from each end of the booster charge before initiating the detonator.

14. The method of claim 11 comprising disposing the output charge of the detonator about half-way between the two ends of the booster charge.

15. The method of claim 11 wherein the cast booster charge has a cylindrical configuration.

16. The method of claim 11 wherein the effective L:D ratio of the booster charge is about 4.6 : 1.

17. The method of claim 11 wherein the borehole has a diameter of about three times the effective diameter of the booster.

18. The method of claim 11 comprising centering the booster charge in the borehole by mounting a stabilizer to the booster charge, the stabilizer comprising a base portion mounted on the booster charge and a vented skirt extending outward from the booster charge.

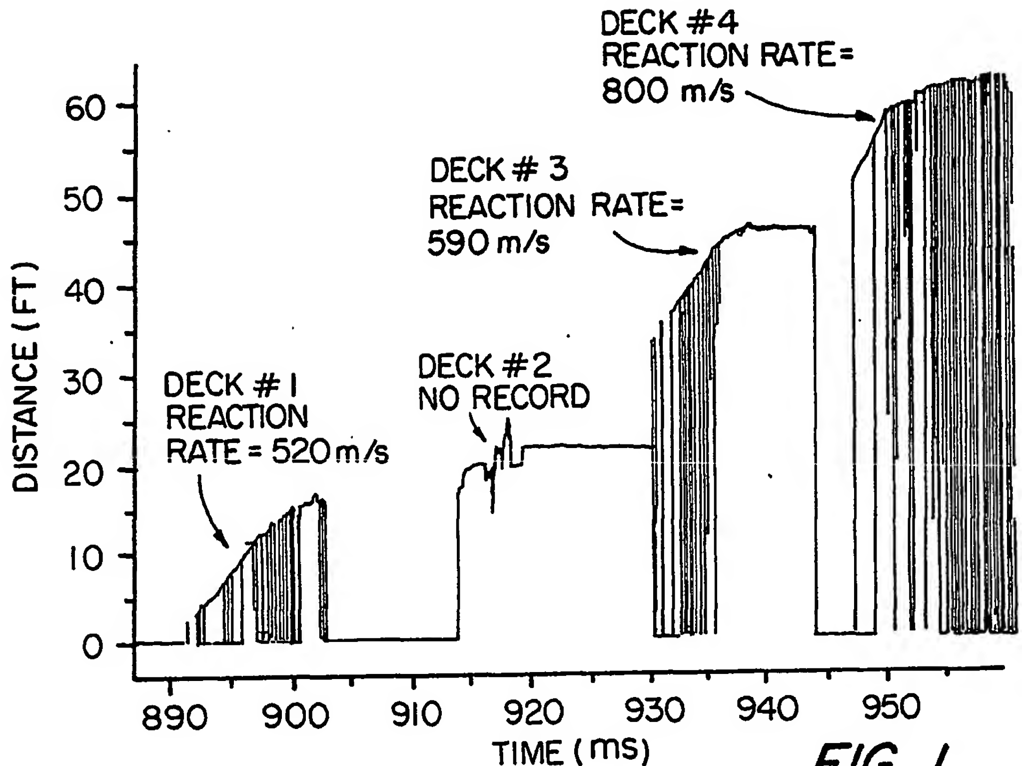


FIG. 1
(PRIOR ART)

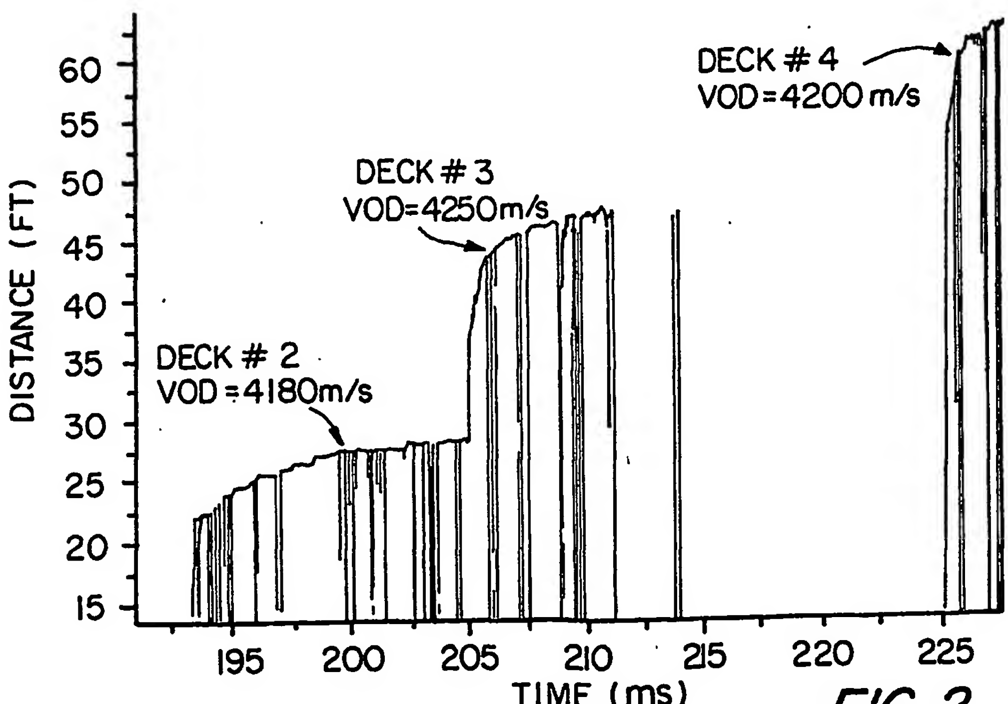


FIG. 2

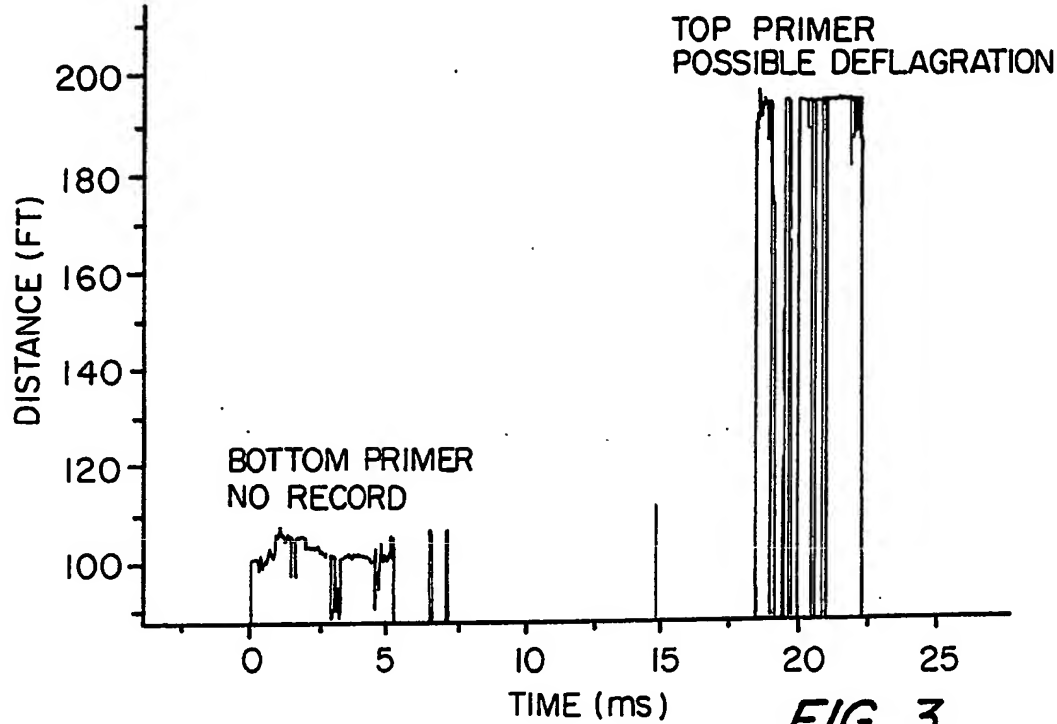


FIG. 3
(PRIOR ART)

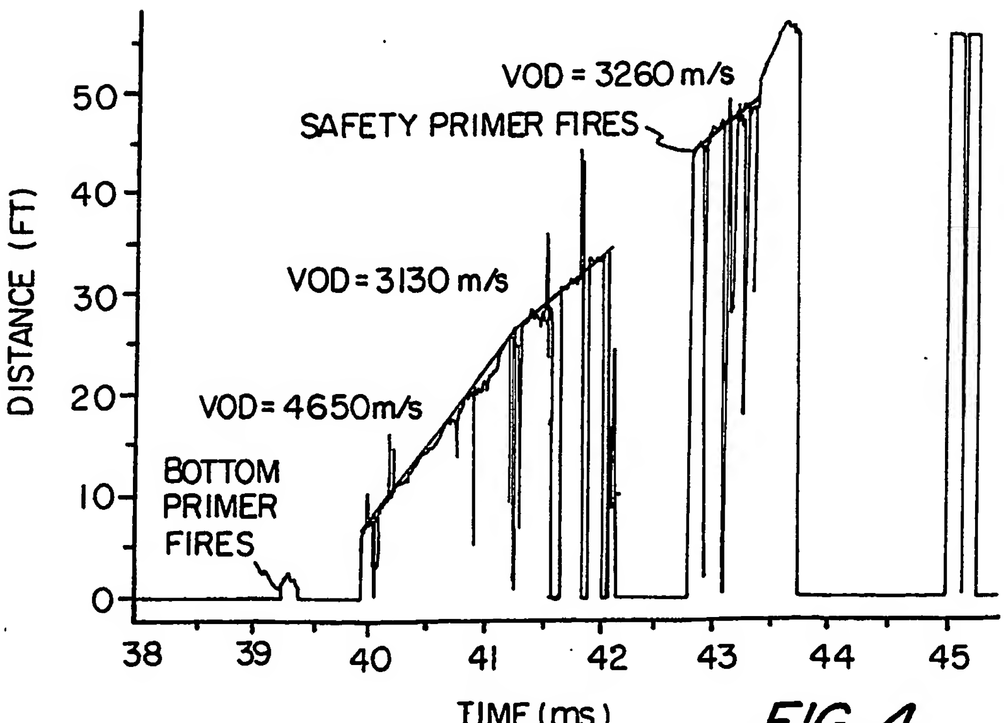


FIG. 4

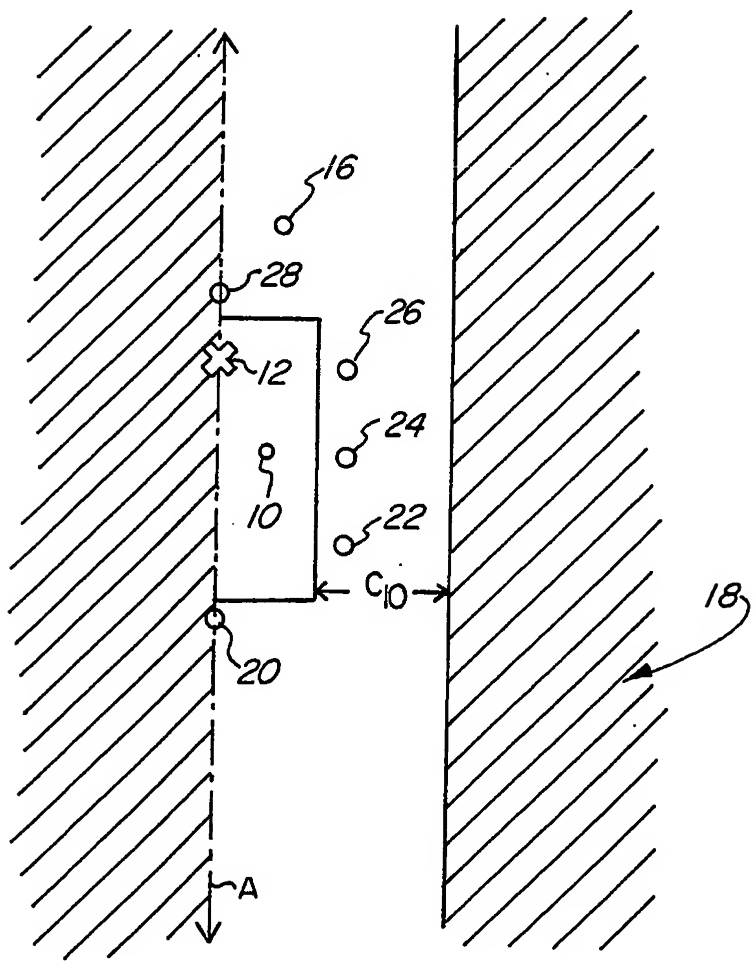


FIG. 5A

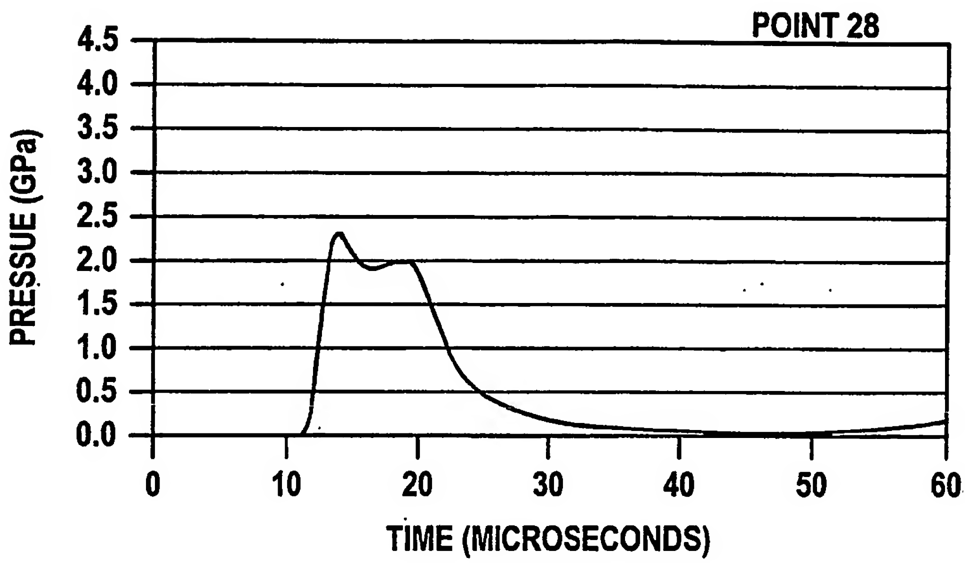

POINT 28
PRESSUE (GPa)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
10
20
30
40
50
60
TIME (MICROSECONDS)

FIG. 5B

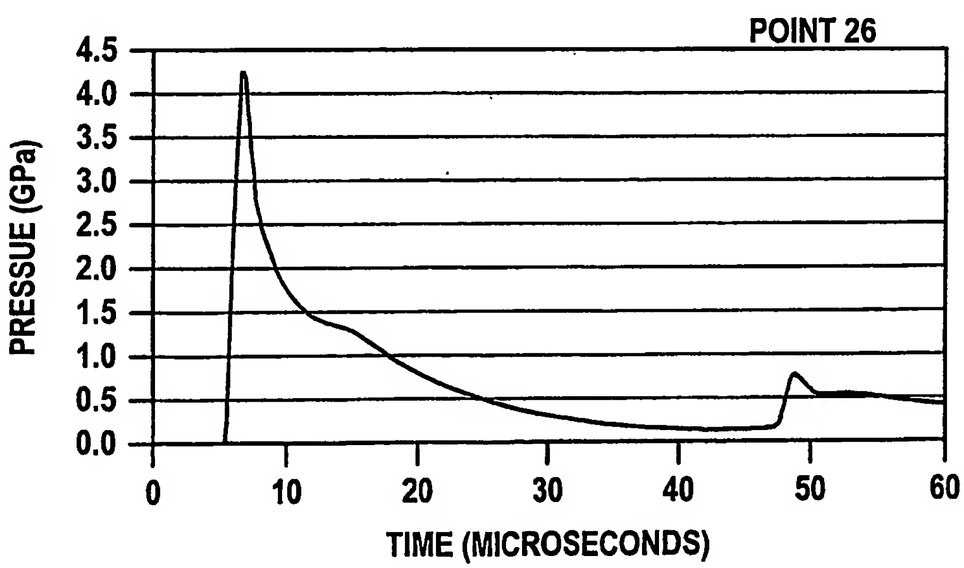

POINT 26
PRESSUE (GPa)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
10
20
30
40
50
60
TIME (MICROSECONDS)

FIG. 5C

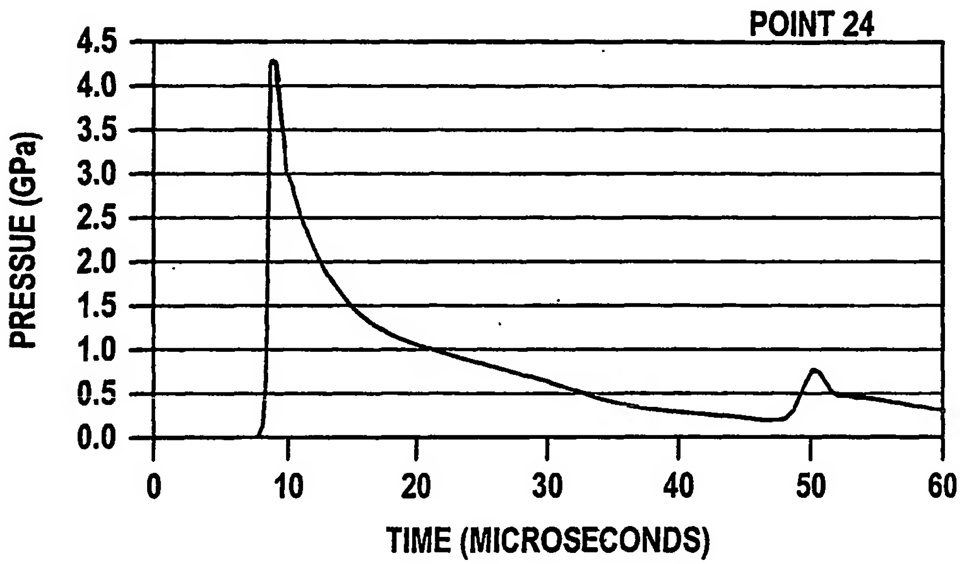

POINT 24
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
PRESSUE (GPa)
0
10
20
30
40
50
60
TIME (MICROSECONDS)

FIG. 5D

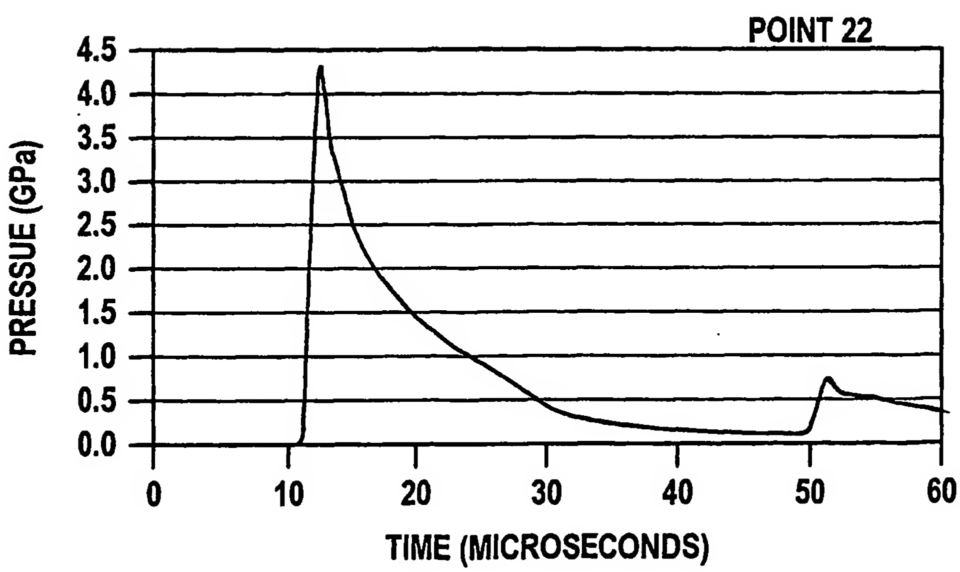
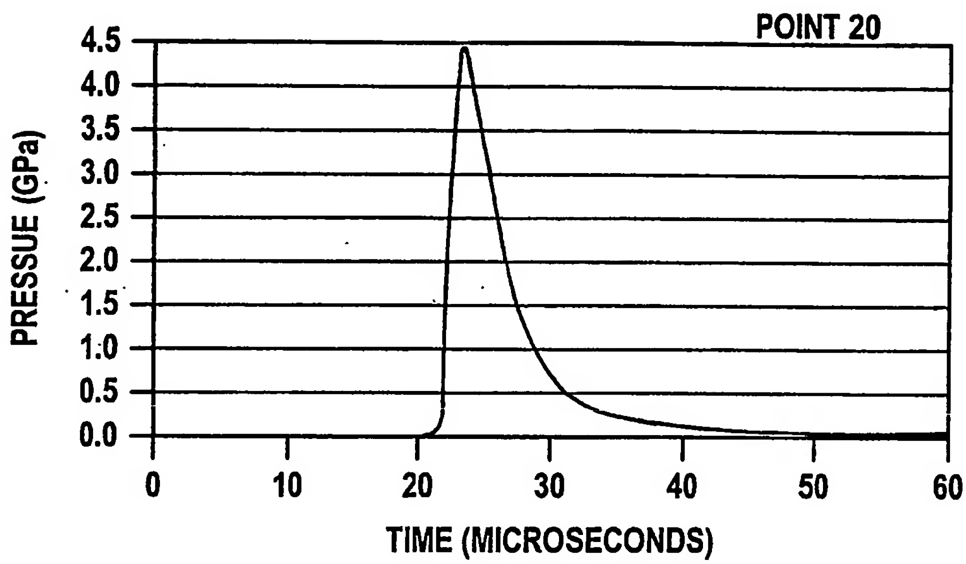

POINT 22
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
PRESSUE (GPa)
0
10
20
30
40
50
60
TIME (MICROSECONDS)

FIG. 5E



POINT 20
PRESSUE (GPa)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
10
20
30
40
50
60
TIME (MICROSECONDS)

FIG. 5F

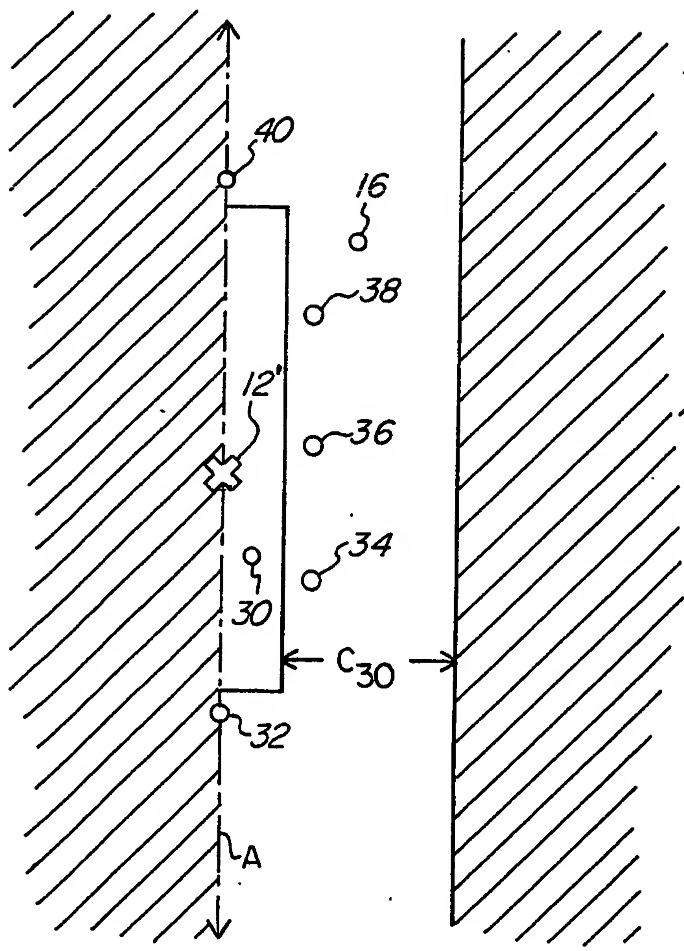


FIG. 6A

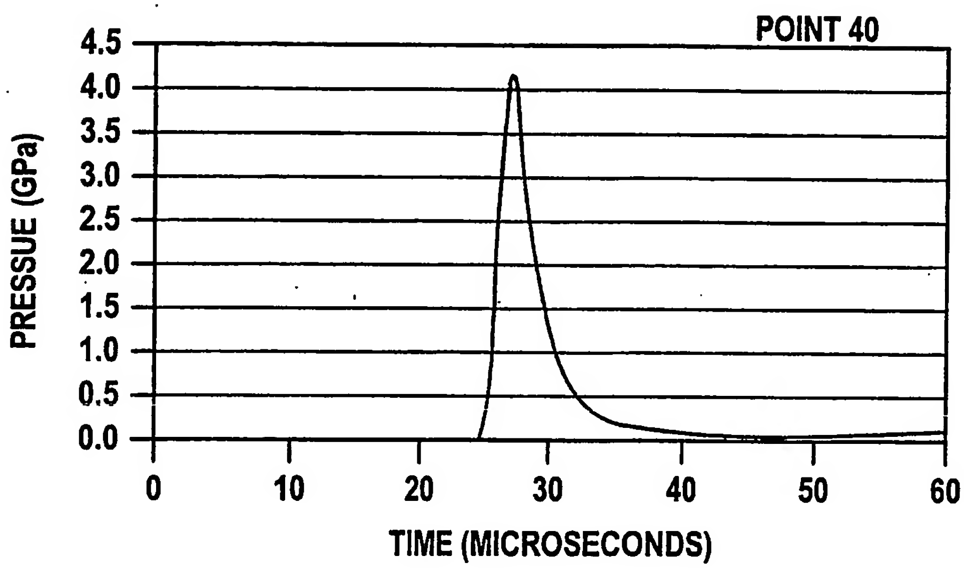

POINT 40
PRESSUE (GPa)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
10
20
30
40
50
60
TIME (MICROSECONDS)

FIG. 6B

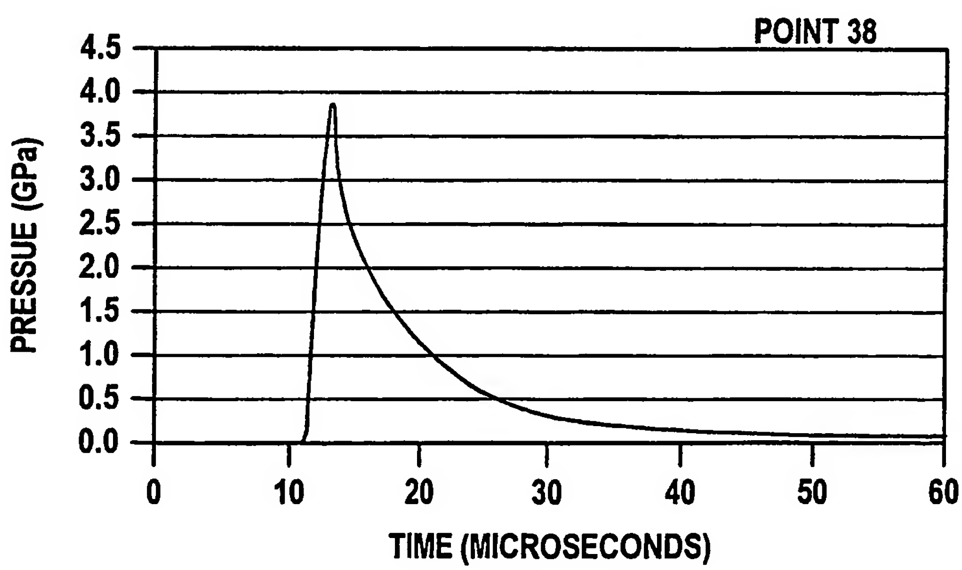

POINT 38
PRESSUE (GPa)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
10
20
30
40
50
60
TIME (MICROSECONDS)

FIG. 6C

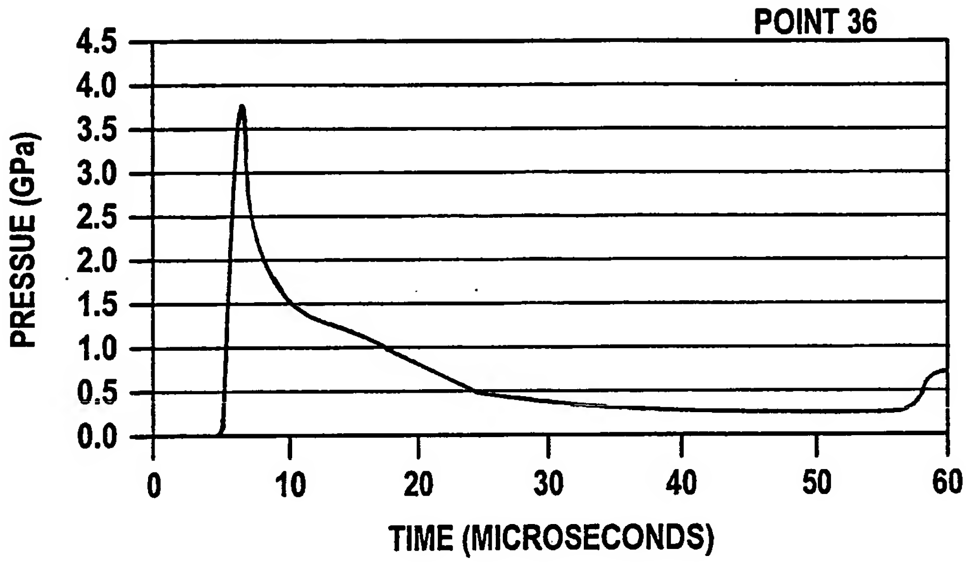

POINT 36
PRESSUE (GPa)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
10
20
30
40
50
60
TIME (MICROSECONDS)

FIG. 6D

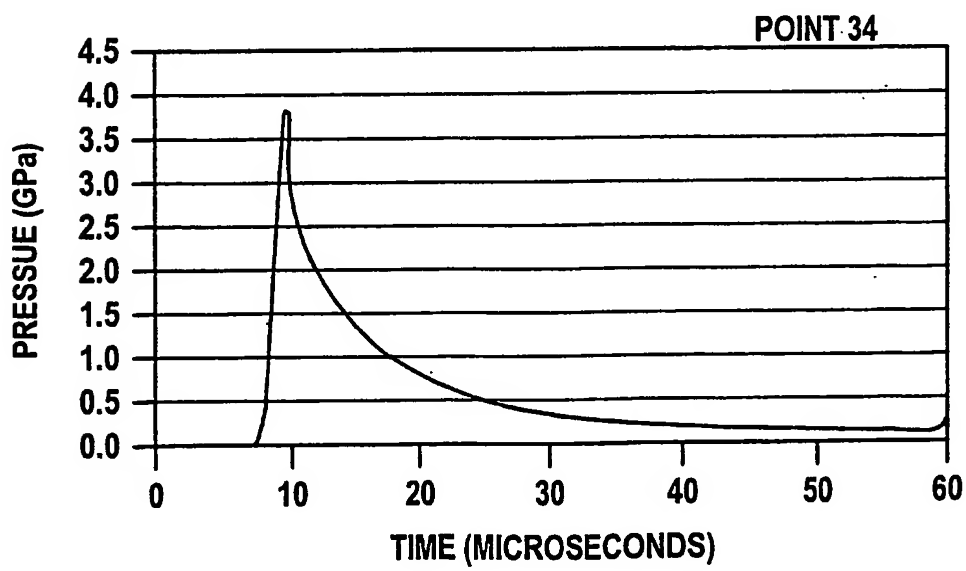

POINT 34
PRESSUE (GPa)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
10
20
30
40
50
60
TIME (MICROSECONDS)

FIG. 6E

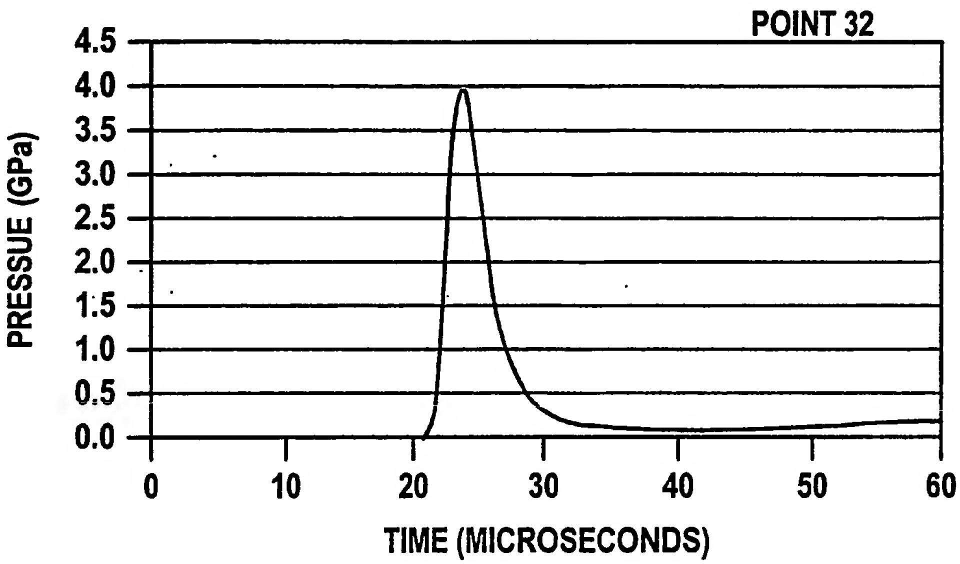

POINT 32
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
PRESSUE (GPa)
0
10
20
30
40
50
60
TIME (MICROSECONDS)

FIG. 6F

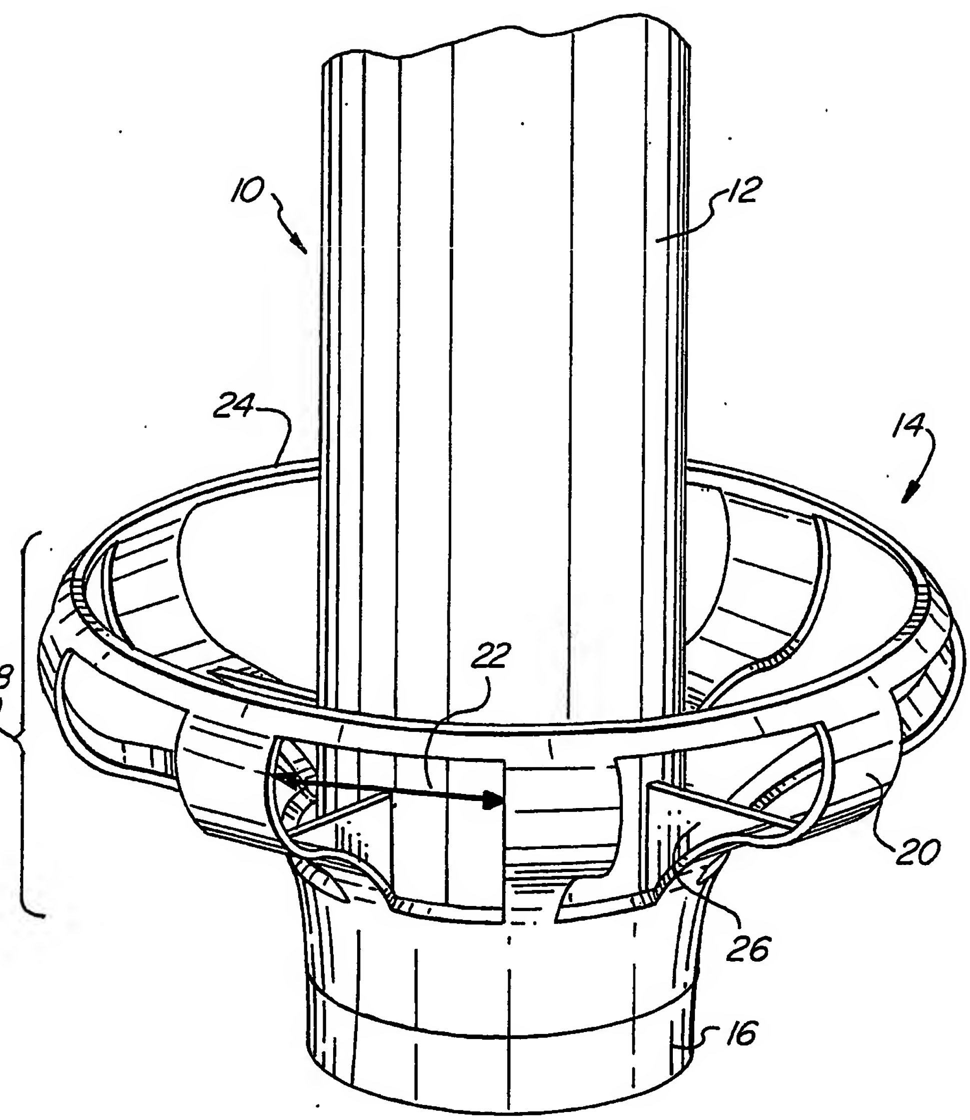


FIG. 7

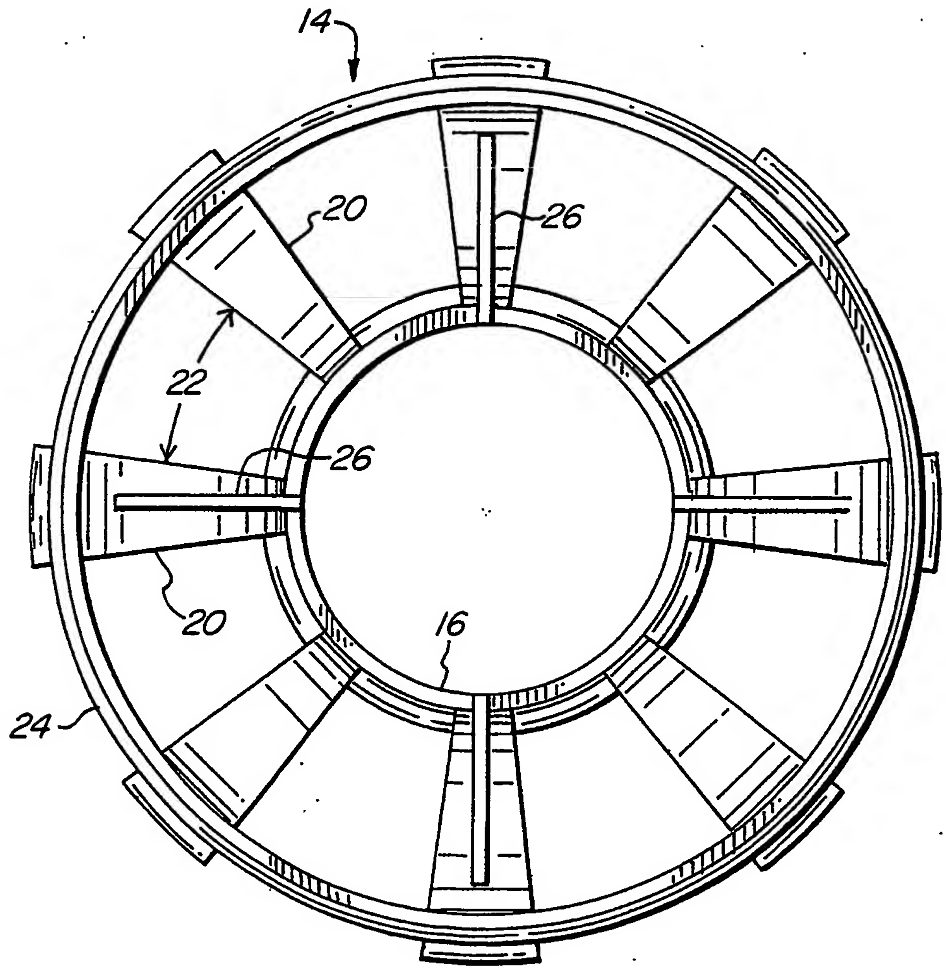


FIG. 8

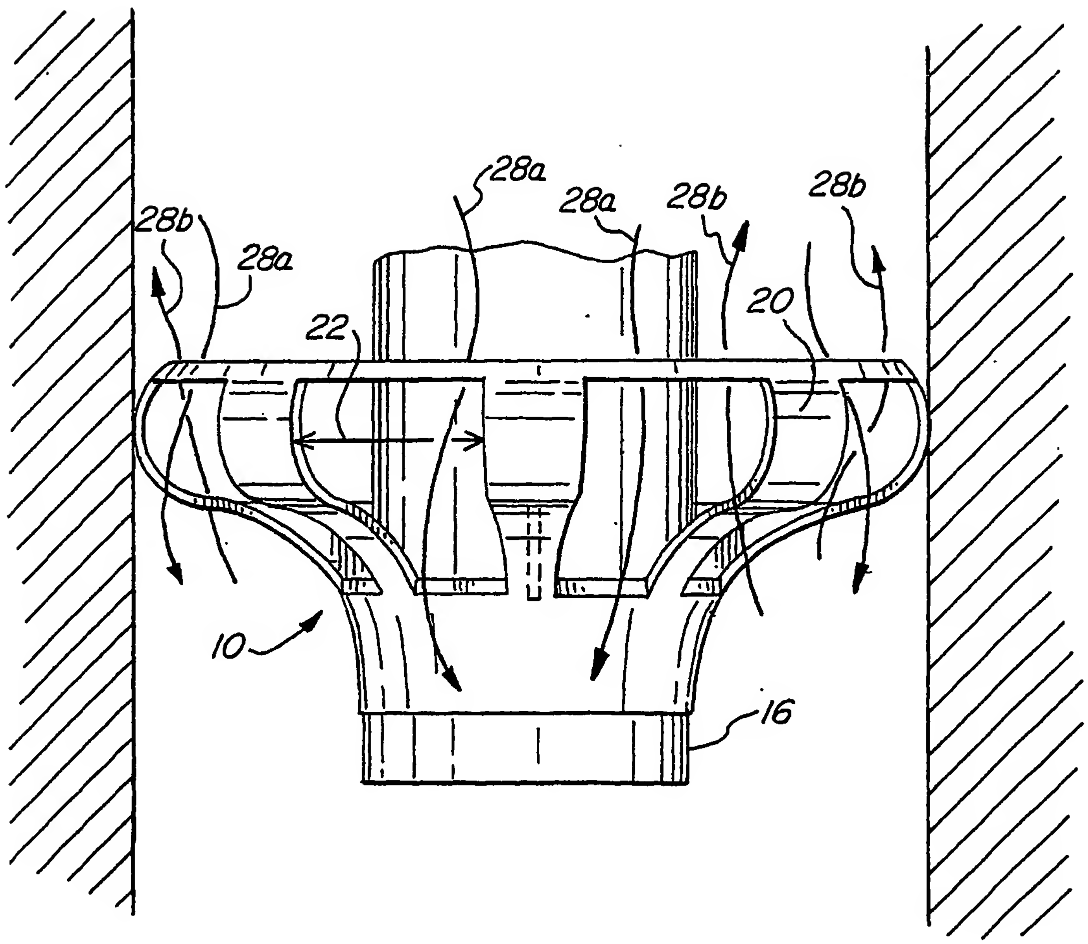


FIG. 9

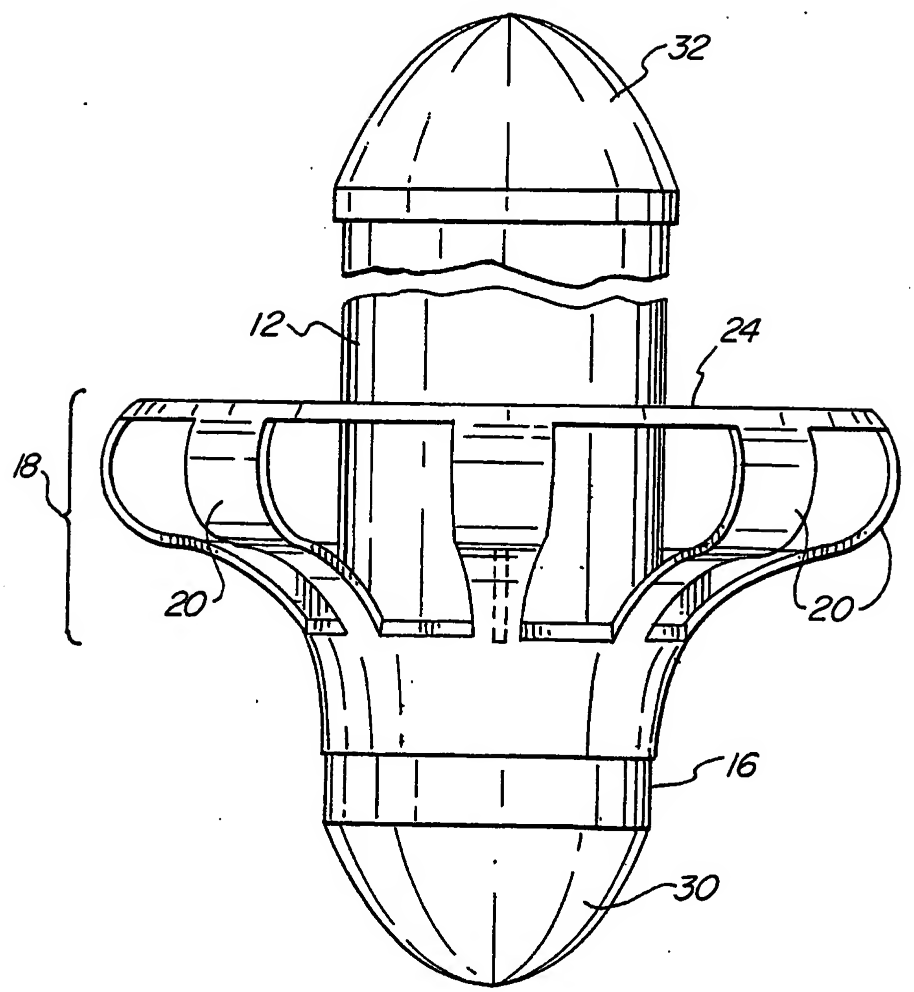


FIG. 10

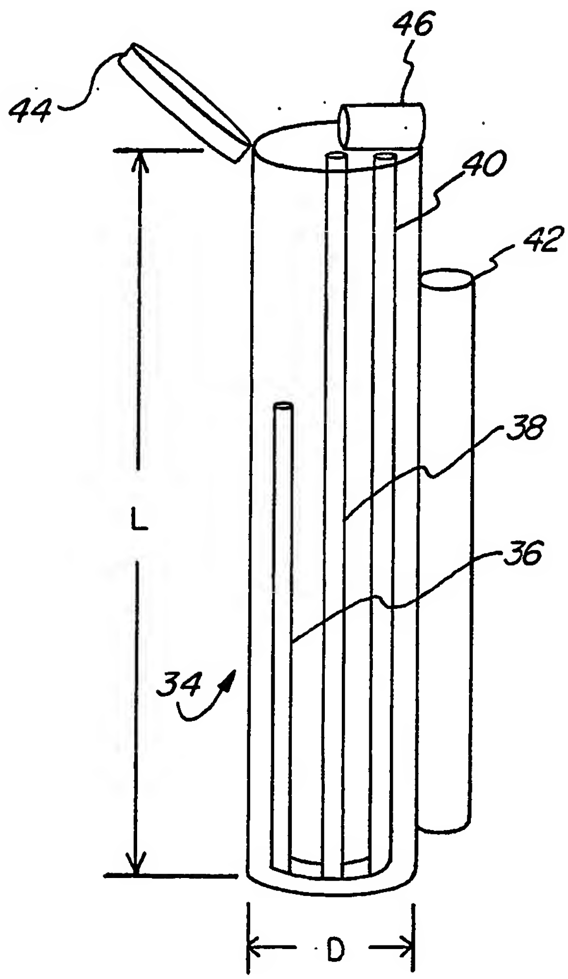


FIG. 11